WIND ENERGY WITH
EMPHASIS ON REDUCED AIR POLLUTION

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WIND ENERGY WITH

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SUMMARY

The reduction of pollutant emissions from electric power plants due to the use of wind power is one of the benefits of using wind power. The plant factor, the ratio of the average generator output power to the generator rated power, is calculated for a 1 MW generator with cut-in speed of 15 mph, rated speed of 30 mph, and feathering speed of 60 mph. The generator is placed 200 feet above the ground. Generators are then distributed through five regions of the country -- New England, Middle Atlantic, East North Central, West North Central, and West South Central -- by assuming that the number of generators per area is proportional to the plant factor. The electric power generated in each region is then found.

Emission factors are obtained for SO_x, NO_x, CO, HC, particulates, and aldehydes due to electric power generation by steam, turbines, and internal combustion engines in each of the five regions. These factors are multiplied by fuel saved, calculated from the wind power generated, to get reduced emissions.

Two damage cost estimates are chosen, Justus (1973) and Waddell (1974), and a net savings is calculated using the reduced emissions. This, plus the savings due to fuel

saved, can be considered to be the savings due to using the wind generator to produce electric power. The savings due to fuel saved (Table 35) are seen to be very much greater than the damage cost savings (Table 46). In the New England Region with 5% wind capacity the ratio of savings due to fuel saved and damage costs savings using Justus' estimates range from 480 to 2390 for proportional fuel replacement and from 1490 to 7340 for most expensive fuel replacement. In the East North Central Region, the ratio ranges from 33 to 164 for proportional fuel replacement and from 1141 to 5642 for most expensive fuel replacement.

CHAPTER I

INTRODUCTION

With the recent rising cost of oil and the realization that our natural fuel resources -- coal, oil, and gas -- will not last forever, there has arisen an interest in alternate forms of energy, such as solar, wind, geothermal, tidal, etc. At present much of work is being done concerning the availability, applicability, and practicality of these energy sources. The ability to use these new energy sources depends on geographical location, time of day, season, and local weather conditions, among other things. This thesis will deal with the availability of wind power in the Continental United States and discuss one of the benefits incurred by the use of wind energy -- the reduction of pollutant emissions from electric power plants.

Chapter Two discusses the wind power data and presents annual plant factors for the Continental United States. These plant factors are then used in Chapter Four to calculate actual power output by wind generators distributed throughout five regions of the country.

Emission factors are given in Chapter Three. The pollutants considered are SO_x, NO_x, CO, HC, particulates, and aldehydes produced during electric power generation by steam, turbine, and internal combustion engines. The emission factors are used with the power output from Chapter IV to give emission reduction for the six pollutants. This is then put in terms of cost by considering two air pollution damage estimates in Chapter VII.

CHAPTER II

WIND POWER

The ability of a wind generator to produce power at a specific location can be expressed as a plant factor, F_p. The plant factor is the average output power of the wind generator, $\bar{P}$, divided by the generator rated power, P_r.

$$F_p = \frac{\bar{P}}{P_r} \tag{1}$$

The average output power depends on the probability distribution of wind speed, p(v), and the power output of the generator as a function of wind speed, P(v), as follows:

$$\bar{P} = \int_0^\infty P(v)p(v)dv \tag{2}$$

Therefore the plant factor can be obtained by knowing the wind speed distribution at the specified location and the operating characteristics of the generator. The plant factor is used here to calculate actual power output of wind generators so the method of its calculation will not be presented in great detail. If more information is desired, see Zimmer et al., 1975.

The wind speed distribution can be obtained from wind measurements made by the National Weather Service. These stations are located throughout the country. A wind speed distribution can be obtained for each site but due to the large number of sites and for ease of comparison, a probability distribution function has been used which best fits the data. Three distribution functions were examined-- Rayleigh, log-normal, and the Weibull. Both the Log-normal and the Weibull fit the data better than the Rayleigh. The Weibull was chosen because it applied over the entire range of wind speed, whereas the Log-normal distribution did not apply as well for winds less than 2 m/s. This would have made very little difference as far as the results are concerned since the data used were only between the speeds of 3.6 m/s (8 mph) and 11.2 m/s (25 mph) because it was assumed that most generators have cut-in and rated speeds within this range.

The Weibull distribution function is:

$$p(v)dv = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] dv \qquad (3)$$

The parameters, c and k, are obtained by fitting a straight line to the Weibull cumulative distribution and are related to the slope, b, and the intercept, a, as follows:

$$c = \exp\left(-\frac{a}{b}\right) \qquad (4)$$
$$k = b$$

The scale parameter, c, has units of speed and is related to the mean wind speed. The shape parameter, k, is inversely related to the variance.

The generator power output as a function of wind speed is assumed to be as follows:

$$P(v) = \begin{cases} 0 & v < v_o \\ \text{increasing with some curvature} & v_o \le v < v_1 \\ P_r & v_1 \le v < v_2 \\ 0 & v > v_2 \end{cases} \tag{5}$$

v_o is the cut-in speed. v_1 is the rated speed, where the generator first operates at rated power. v_2 is the feathering speed, where the generator is shut down to avoid damage. For $v_o \le v < v_1$ the curvature is approximated as parabolic, $P(v) = A + Bv + Cv^2$, where A, B, and C are determined by:

$$P(v_o) = A + Bv_o + Cv_o^2 = 0 \tag{6}$$

$$P(v_1) = A + Bv_1 + Cv_1^2 = P_r \tag{7}$$

and the assumption

$$P(v_c) = A + Bv_c + Cv_c^2 = P_c \tag{8}$$

$$v_c = \frac{v_o + v_1}{2} \tag{9}$$

$$P_c = P_r \left(\frac{v_c}{v_1}\right)^3 \tag{10}$$

The operating characteristics and parabolic approximation are shown in Figure 1. This is for the NASA Plumbrook unit with $v_o = 3.6$ m/s, $v_1 = 8.0$ m/s, $v_2 = 26.8$ m/s and $P_r = 100$ kW (generator output).

The average output power, $\bar{P}$, can now be evaluated as follows:

$$\begin{aligned}\bar{P} &= \int_{o}^{\infty} P(v)_{p}(v)dv \\ &= \int_{v_o}^{v_1} (A + Bv + Cv^2)p(v)dv + \int_{v_1}^{v_2} P_r p(v)dv\end{aligned} \tag{11}$$

A computer program was written to take v_o, v_1, v_2, P_r, and for each c and k input, compute F_p and other generator power characteristics. Figure 2 shows the annual plant factor for a 1 MW generator at 200 feet with v_o = 15 mph, v_1 = 30 mph, and v_2 = 60 mph.

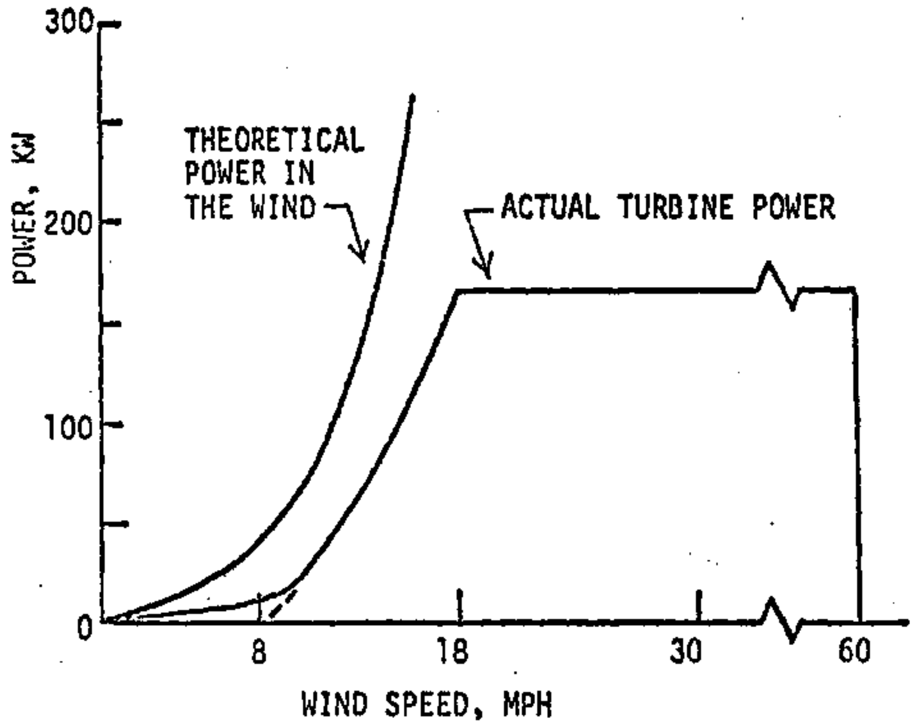

Figure 1. Operating Characteristics For NASA's Plumbrook Unit.

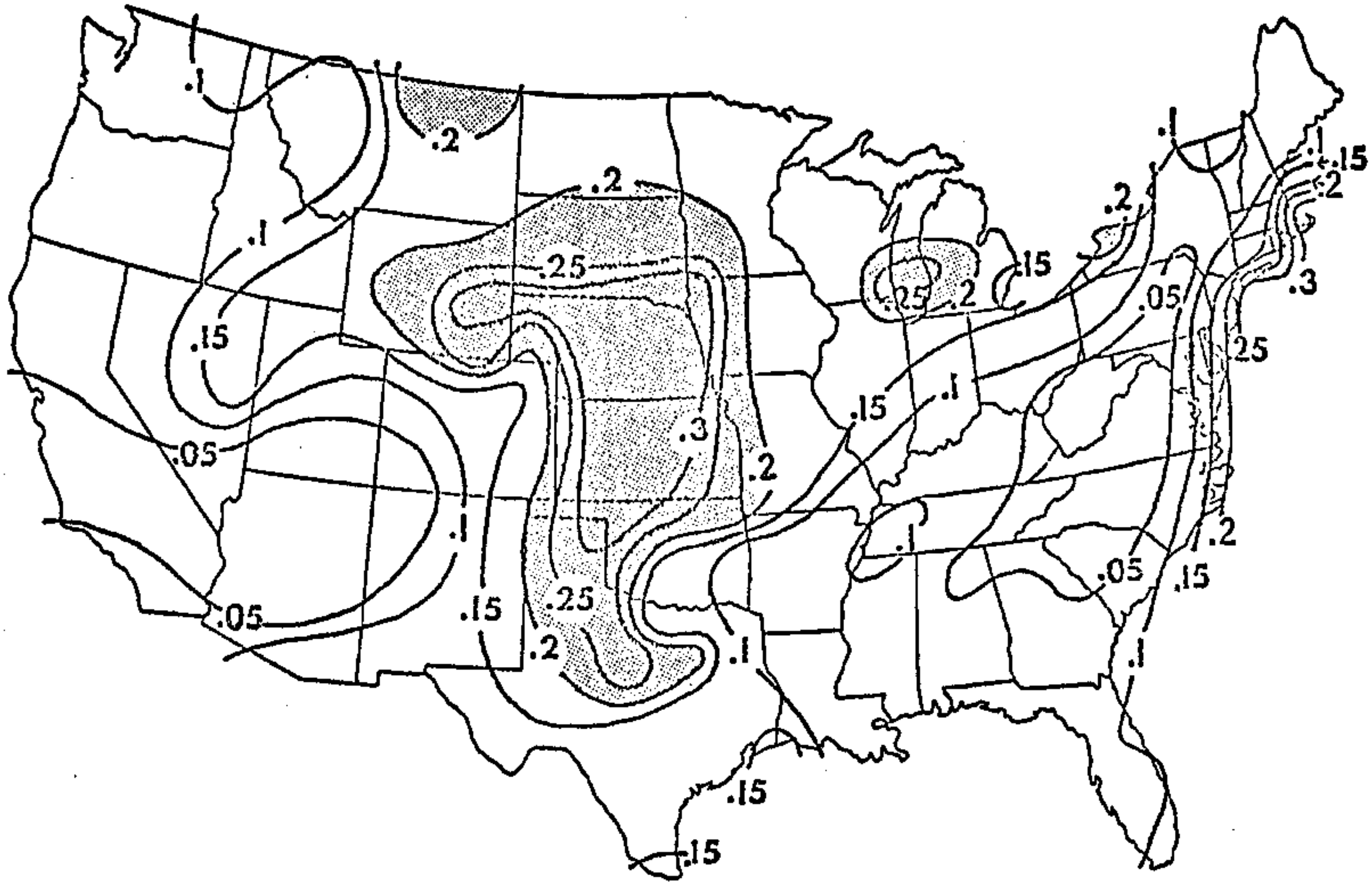

Figure 2. Annual Plant Factor For a 1 MW Generator at 200 Feet.

CHAPTER III

EMISSION FACTORS

The emission factor is an average rate at which a pollutant is released as a result of a specified action. Since it is an average, the emission factor cannot be applied with any degree of validity to a single process. The validity increases as a large number of processes are considered and for a nationwide study the emission factor can be a very useful estimator. The emission factor will be used here to estimate reduced emissions from electric power plants due to the use of wind generated electricity.

The pollutants considered are SO_x, NO_x, CO, HC, particulates, and aldehydes released during electric power generation by steam, turbines, and internal combustion engines. Calculations will be made for five regions of the country, as shown in Figure 3. These regions are used by the Federal Power Commission to publish data on fuel used, electric power produced, etc. The emission factors by pollutant, region, and process are given in Table 1 - Table 6.

The emission factors for SO_x - steam - coal were taken from a nomograph in Smith (1966), using the sulfur content and heating values given in Table 7. The SO_x - steam - oil values were taken from Smith (1962) and Environmental Protection Agency (1972) with sulfur contents as in Table 7. The rest of the SO_x factors were taken from Environmental Protection Agency (1975). All SO_x factors were multiplied by .9 to account for some degree of control.

Smith (1966) gives emission factors for the other pollutants for steam-coal as follows:

Pollutant	Emission Factor	
NO_x	.8	lb/10^6Btu
CO	.02	lb/10^6Btu
HC	.007	lb/10^6Btu
Aldehydes	.0002	lb/10^6BTU
Particulates	25	lb/TON

The particulate factor was for "average" degrees of control. These values were used with the heating values from Table 7 to obtain the final emission factors.

The remaining emission factors were taken from Environmental Protection Agency (1975). Particulates were multiplied by .2 to account for controls. All other pollutants are considered uncontrolled.

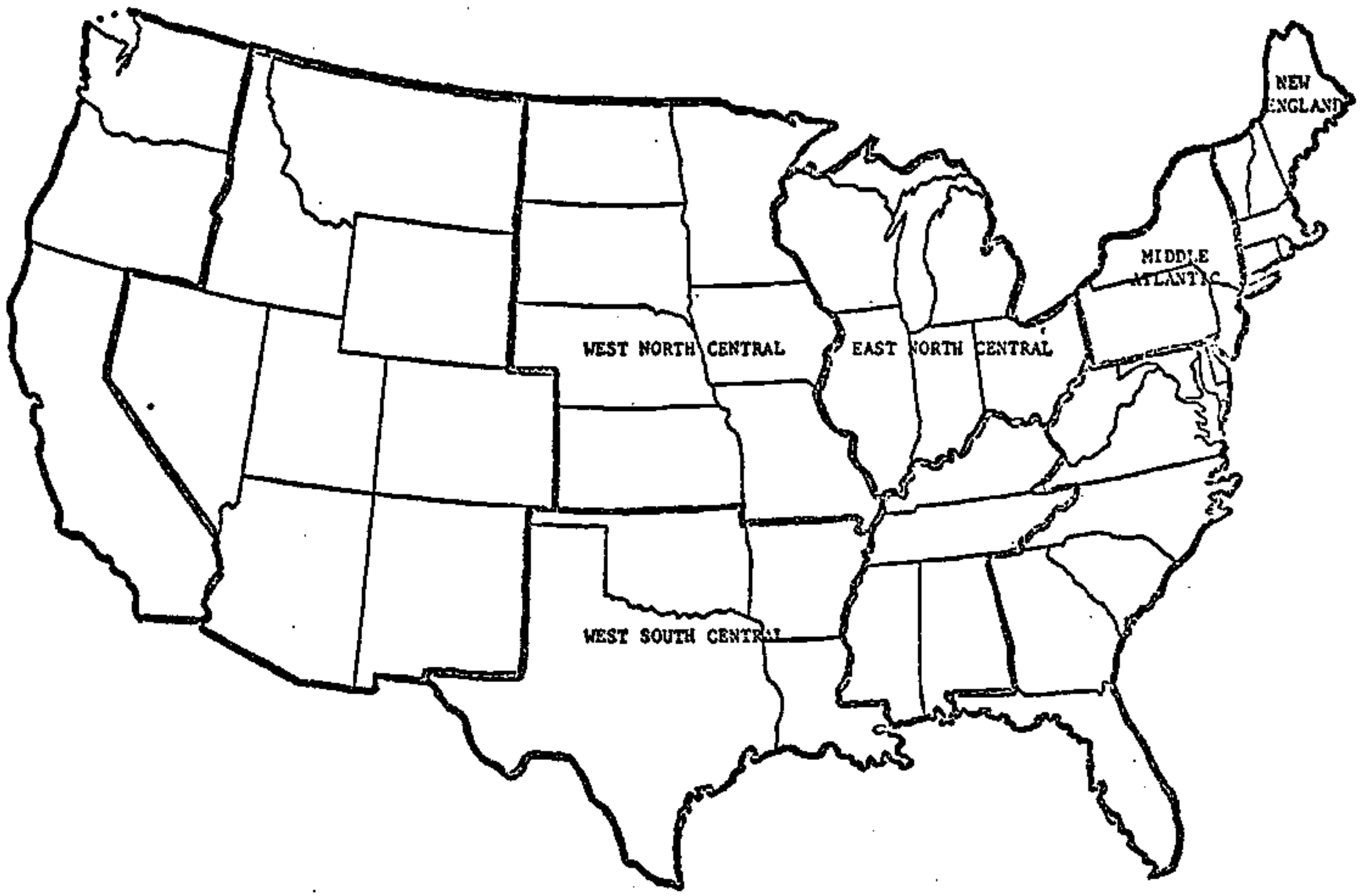

Figure 3. Selected Regions of the United States.

Table 1. Emission Factors by Region and Process - SO_x*

Region	Steam			Turbine		Int. Combustion	
	Coal	Oil	Gas	Oil	Gas	Oil	Gas
New England	47.1	4.81	.54+	.132-	4.68†	.132-	4.68†
Middle Atlantic	71.1	4.81	.54+	.132-	4.68†	.132-	4.68†
East North Central	93.3	4.81	.54+	.132-	4.68†	.132-	4.68†
West North Central	80.1	7.21	.54+	.132-	4.68†	.132-	4.68†
West South Central	20.2	4.20	.54+	.132-	4.68†	.132-	4.68†

* Units: Coal, Lb/Ton; Oil, Lb/Bbl; Gas, Lb/10^6cf.
+ Based on Average Sulfur Content of 4600 g/10^6cf.
- Based on .05% Sulfur Content by Weight.
† From Experimental Data.

Table 2. Emission Factors by Region and Process - NO_x*

Region	Steam			Turbine		Int. Combustion	
	Coal	Oil	Gas	Oil	Gas	Oil	Gas
New England	19.9	4.41	390	2.85	413	2.85	413
Middle Atlantic	19.1	4.41	390	2.85	413	2.85	413
East North Central	17.7	4.41	390	2.85	413	2.85	413
West North Central	15.8	4.41	390	2.85	413	2.85	413
West South Central	11.2	4.41	390	2.85	413	2.85	413

* Units: Coal, Lb/Ton; Oil, Lb/Bbl; Gas, Lb/10^6cf.

Table 3. Emission Factors by Region and Process - CO*

Region	Steam			Turbine		Int. Combustion	
	Coal	Oil	Gas	Oil	Gas	Oil	Gas
New England	.50	.00168	.4	.647	115	.647	115
Middle Atlantic	.49	.00168	.4	.647	115	.647	115
East North Central	.44	.00168	.4	.647	115	.647	115
West North Central	.40	.00168	.4	.647	115	.647	115
West South Central	.28	.00168	.4	.647	115	.647	115

* Units: Coal, Lb/Ton; Oil, Lb/Bbl; Gas, Lb/10^6cf.

Table 4. Emission Factors by Region and Process - HC*

Region	Steam			Turbine		Int. Combustion	
	Coal	Oil	Gas	Oil	Gas	Oil	Gas
New England	.174	.084	40	.234	42	.234	42
Middle Atlantic	.168	.084	40	.234	42	.234	42
East North Central	.154	.084	40	.234	42	.234	42
West North Central	.138	.084	40	.234	42	.234	42
West South Central	.098	.084	40	.234	42	.234	42

* Units: Coal, Lb/Ton; Oil, Lb/Bbl; Gas, Lb/10^6cf.

Table 5. Emission Factors by Region and Process - Aldehydes*

Region	Steam			Turbine		Int. Combustion	
	Coal	Oil	Gas	Oil	Gas	Oil	Gas
New England	.00498	.042	3	NA	NA	NA	NA
Middle Atlantic	.00479	.042	3	NA	NA	NA	NA
East North Central	.00441	.042	3	NA	NA	NA	NA
West North Central	.00396	.042	3	NA	NA	NA	NA
West South Central	.00280	.042	3	NA	NA	NA	NA

* Units: Coal, Lb/Ton; Oil, Lb/Bbl; Gas, Lb/10^6cf.
NA: Not Available

Table 6. Emission Factors by Region and Process - Particulates*

Region	Steam			Turbine		Int. Combustion	
	Coal	Oil	Gas	Oil	Gas	Oil	Gas
All Regions	25	.067	3	.042	2.8	.042	2.8

* Units: Coal, Lb/Ton; Oil, Lb/Bbl; Gas, Lb/10^6cf.

Table 7. Sulfur Content and Heating Values by Region

Region	Average Sulfur Content* Steam-coal % weight	Average Sulfur Content+ Steam-oil % weight	Heating Values† Btu/lb
New England	1.4	.8	12460
Middle Atlantic	2.1	.8	11965
East North Central	2.8	.8	11035
West North Central	2.3	1.2	9890
West South Central	.6	.7	7000

* FPC News Release No. 21376
+ FPC News Release No. 21376
† From Zimmer et al. (1975)

CHAPTER IV

DISTRIBUTION OF WIND GENERATORS

In order to calculate wind generated energy it is necessary to assume some installed wind generator capacity. For each region it will be assumed that the installed wind generating capacity is 5%, 10%, and 20% of the total installed capacity. (See Table 8).

Distributing the generators in each region will be done as follows. One mega-watt generators will be used with the annual plant factor given in Figure 2. There are no generators in areas with plant factor less than 10%. In other areas, the number of generators per area is assumed to be proportional to the plant factor, as follows:

$$\frac{\text{Number of generators}}{\text{Area}} \propto \text{Plant Factor} \qquad (12)$$

Using this approach gives the number of 1 MW units installed in each plant factor category for each region as in Table 9.

To obtain the energy generated per region, plant factors of 12.5, 17.5, 22.5, 27.5, and 32 percent were multiplied by the number of generators in their respective categories and totaled. This total was then multiplied by 8766 hr/yr to get kilowatt hours. (See Table 10).

Table 8. Installed Wind Generator Capacity (10^6 kw)

Electrical Generating Capacity		Assumed Wind Generator Capacity		
Region	Total Installed Capacity*	5% of Total	10% of Total	20% of Total
New England	17.1	.854	1.71	3.42
Middle Atlantic	61	3.05	6.10	12.2
East North Central	81.6	4.08	8.16	16.3
West North Central	32	1.60	3.20	6.39
West South Central	53.7	2.68	5.37	10.7

* As of December 31, 1973

Table 9. Installed 1 MW Units for Each Region and Plant Factor Category.

		Plant Factor, %					
Region		10-15	15-20	20-25	25-30	30	Total
New England	5%	311	166	133	111	130	851
	10%	621	333	266	222	266	1708
	20%	1242	666	532	444	532	3416
Middle Atlantic	5%	1355	1016	678	0	0	3049
	10%	2710	2033	1355	0	0	6090
	20%	5422	4067	2711	0	0	12200
East North Central	5%	954	2226	636	265	0	4081
	10%	1908	4452	1272	530	0	8162
	20%	3815	8903	2543	1059	0	16320
West North Central	5%	21	410	378	158	631	1596
	10%	42	820	758	315	1262	3197
	20%	84	1641	1514	631	2524	6394
West South Central	5%	661	495	661	620	248	2685
	10%	1322	991	1322	1239	496	5370
	20%	2644	1983	2644	2478	991	10740

Table 10. Wind Energy Generated per Region

Region		Average Power Generated (MW)	Energy Produced (10^6 kWh)
New England	5%	170.9	1.50
	10%	341.9	3
	20%	683.1	6
Middle Atlantic	5%	449.7	4.38
	10%	999.4	8.76
	20%	1999.4	17.53
East North Central	5%	724.8	6.35
	10%	1449.6	12.71
	20%	2898.3	25.41
West North Central	5%	404.8	3.55
	10%	809.8	7.10
	20%	1619.5	14.20
West South Central	5%	567.8	4.98
	10%	1135.6	9.95
	20%	2271	19.91

CHAPTER V

ENERGY USE DATA

The data presented here will be used for calculating emission reduction in Chapter VI.

Heating values by region and fuel are given in Table 11. Energy and fuel use data were obtained from Zimmer et al., (1975) and Federal Power Commission News Release #20333 These data are presented by region and process in Table 12 - Table 16.

Table 11

Heating Values by Region and Fuel*

Region	Coal, Btu/ton	Oil, Btu/BBL	Gas, Btu/MCF+
New England	2.492×10^7	6.126×10^6	1.002×10^6
Middle Atlantic	2.393×10^7	6.099×10^6	1.093×10^6
East North Central	2.207×10^7	6.098×10^6	$.878 \times 10^6$
West North Central	1.978×10^7	6.223×10^6	$.992 \times 10^6$
West South Central	1.400×10^7	6.101×10^6	1.029×10^6

*From Zimmer et al., (1975).

+ MCF = Thousand cubic feet

Table 12. Electrical Power Produced and Fuel Consumed for the New England Region for 1973

Process	Fuel	Fuel Used	Energy Consumed (Btu)	Energy Consumed (Percent)	Energy Produced (kWh)	Energy Produced (Percent)	Efficiency (Percent)
Steam	Coal	1.121×10^{6} Tons	2.794×10^{13}	4.98		3.65*	
	Oil	8.377×10^{7} Bbls	5.132×10^{14}	91.50	5.149×10^{10}	66.98*	32.14
	Gas	5.368×10^{6} Mcf	5.379×10^{12}	.96		.70*	
Turbine	Oil	1.703×10^{6} Bbls	1.043×10^{13}	1.86	6.629×10^{8}	.90*	21.15
	Gas	2.647×10^{5} Mcf	2.652×10^{11}	.05		.02*	
Internal Combustion	Oil	5.163×10^{5} Bbls	3.163×10^{12}	.56	3.091×10^{8}	.37*	28.82
	Gas	4.956×10^{5} Mcf	4.966×10^{11}	.09		.06*	
Nuclear					1.437×10^{10}	19.91	
Hydroelectric					5.353×10^{9}	7.42	

* Assuming that the efficiency of the process remains constant for equal amounts of energy from different fuels.

Table 13. Electrical Power Produced and Fuel Consumed for the Middle Atlantic Region for 1973

Process	Fuel	Fuel Used	Energy Consumed (Btu)	Energy Consumed (Percent)	Energy Produced (kWh)	Energy Produced (Percent)	Efficiency (Percent)
Steam	Coal	4.697×10^7 Tons	1.124×10^{15}	50.57		43.16*	
	Oil	1.405×10^8 Bbls	8.569×10^{14}	38.55	1.935×10^{11}	32.90*	32.16
	Gas	6.573×10^7 Mcf	7.184×10^{13}	3.23		2.76*	
Turbine	Oil	2.176×10^7 Bbls	1.327×10^{14}	5.97	1.028×10^{10}	3.35*	21.10
	Gas	3.064×10^7 Mcf	3.349×10^{13}	1.51		.84*	
Internal Combustion	Oil	5.035×10^5 Bbls	3.070×10^{12}	.14	3.255×10^8	.11*	30.70
	Gas	5.007×10^5 Mcf	5.473×10^{11}	.02		.02*	
Nuclear					1.117×10^{10}	4.55	
Hydroelectric					3.019×10^{10}	12.30	

* Assuming the efficiency of the process remains constant for equal amounts of energy from different fuels.

Table 14. Electrical Power Produced and Fuel Consumed for the East North Central Region for 1973

Process	Fuel	Fuel Used	Energy Consumed (Btu)	Energy Consumed (Percent)	Energy Produced (kWh)	Energy Produced (Percent)	Efficiency (Percent)
Steam	Coal	1.334×10^{8} Tons	2.944×10^{15}	90.67		82.74*	
	Oil	2.157×10^{7} Bbls	1.315×10^{14}	4.05	3.051×10^{11}	3.70*	33.04
	Gas	8.526×10^{7} Mcf	7.486×10^{13}	2.31		2.10*	
Turbine	Oil	6.624×10^{6} Bbls	4.039×10^{13}	1.24	5.497×10^{9}	.78*	22.65
	Gas	4.830×10^{7} Mcf	4.241×10^{13}	1.31		.82*	
Internal Combustion	Oil	1.043×10^{6} Bbls	6.360×10^{12}	.20	1.316×10^{9}	.17*	32.19
	Gas	8.641×10^{6} Mcf	7.587×10^{12}	.23		.21*	
Nuclear					2.884×10^{10}	8.37	
Hydroelectric					3.854×10^{9}	1.12	

* Assuming that the efficiency of the process remains constant for equal amounts of energy from different fuels.

Table 15. Electrical Power Produced and Fuel Consumed for the West North Central Region for 1973

Process	Fuel	Fuel Used	Energy Consumed (Btu)	Energy Consumed (Percent)	Energy Produced (kWh)	Energy Produced (Percent)	Efficiency (Percent)
Steam	Coal	3.549×10^7 Tons	7.016×10^{14}	61.79		53.50*	
	Oil	2.742×10^6 Bbls	1.705×10^{13}	1.50	9.620×10^{10}	1.3*	30.30
	Gas	3.694×10^8 Mcf	3.664×10^{14}	32.27		28.00*	
Turbine	Oil	1.227×10^6 Bbls	7.629×10^{12}	.67	1.536×10^9	.40*	22.60
	Gas	1.568×10^7 Mcf	1.555×10^{13}	1.37		.90*	
Internal Combustion	Oil	8.222×10^5 Bbls	5.112×10^{12}	.45	2.291×10^9	.40*	28.60
	Gas	2.237×10^7 Mcf	2.219×10^{13}	1.95		1.60*	
Nuclear					3.869×10^9	3.30	
Hydroelectric					1.234×10^{10}	10.60	

* Assuming that the efficiency of the process remains constant for equal amounts of energy from different fuels.

Table 16. Electrical Power Produced and Fuel Consumed for the West South Central Region for 1973

Process	Fuel	Fuel Used	Energy Consumed (Btu)	Energy Consumed (Percent)	Energy Produced (kWh)	Energy Produced (Percent)	Efficiency (Percent)
Steam	Coal	4.733×10^{6} Tons	6.626×10^{13}	3.06		2.93*	
	Oil	2.094×10^{7} Bbls	1.278×10^{14}	5.90	2.063×10^{11}	5.65*	32.83
	Gas	1.895×10^{9} Mcf	1.950×10^{15}	89.97		86.15*	
Turbine	Oil	3.792×10^{4} Bbls	2.313×10^{11}	.01	8.575×10^{8}	.01*	23.02
	Gas	1.213×10^{7} Mcf	1.248×10^{13}	.58		.38*	
Internal Combustion	Oil	2.142×10^{5} Bbls	1.307×10^{12}	.06	8.487×10^{8}	.05*	27.38
	Gas	9.006×10^{6} Mcf	9.267×10^{12}	.43		.34*	
Nuclear					0		
Hydroelectric					9.799×10^{9}	4.50	

* Assuming that the efficiency of the process remains constant for equal amounts of energy from different fuels.

CHAPTER VI

REDUCED EMISSION

The calculations of emission reduction due to the wind power production in Table 10 requires some assumption as to which process the energy is to replace. Two different approaches will be taken here. In the first assumption, the energy is distributed among the different processes in the same proportion as they use fuel. Fuel comparisons will be made on the basis of Btu's and the wind energy distributed among the processes as the percentage of Btu's each process uses. The wind energy is then converted to Btu's saved by the equation below and then to fuel saved by using the heating values of Table 11. (See Table 17 and Table 18.) The appropriate emission factor is then applied to the fuel saved to get reduced emissions (see Table 19 - Table 24).

$$\frac{\text{kWh } (3.415 \times 10^3)}{\text{Efficiency}} = \text{Btu} \qquad (13)$$

In the second assumption the energy is distributed among the processes as a replacement for the most expensive fuels. The cost of fuel for each region is shown in Figure 4 - Figure 8. A cost is chosen in terms of Btu's and converted to cost/kWh. (See Table 25 and Table 26.) The wind energy is used to replace the most expensive fuel in each region, then the second most expensive and so on until all the energy is distributed. Btu's saved, fuel saved, and reduced emission are then calculated as above. (See Table 27 - Table 34.)

Replacing the most expensive process with wind energy (Approach 2) would be the ideal situation but cannot realistically be expected to occur. So this will overestimate the savings produced by wind energy. But proportional fuel replacement (Approach 1) seems equally unrealistic since the power company will at least replace the most expensive process that is operating at the time. So this is an underestimate of the savings. The real cost savings would seem to be somewhere in between the two approaches taken here.

Besides the reduction in damage costs, there is also a cost savings due to having to buy less fuel. This is found by multiplying the fuel saved by the cost. (See Table 35.)

Table 17. Energy Distribution by Process and Region - Proportional Fuel Replacement (10^7 kWh)

Region	Wind Capacity	Steam			Turbine		Internal Combustion	
		Coal	Oil	Gas	Oil	Gas	Oil	Gas
	5%	7.46	137	1.44	2.97	.0704	.839	.133
New England	10%	14.9	274	2.88	5.57	.141	1.68	.267
	20%	29.8	548	5.75	11.1	.282	3.35	.533
	5%	222	169	14.1	26.2	6.61	.605	.108
Middle Atlantic	10%	443	338	28.3	52.3	13.2	1.21	.216
	20%	886	675	56.6	105.	26.5	2.42	.431
	5%	576	25.7	14.7	7.88	8.33	1.25	1.49
East North Central	10%	1150	51.8	29.4	15.8	16.7	2.49	2.97
	20%	2300	103	58.7	31.5	33.3	4.98	5.95
	5%	219	5.32	115	2.38	4.86	1.60	6.92
West North Central	10%	439	10.6	229	4.76	9.72	3.19	13.8
	20%	877	21.3	458	9.53	19.4	6.39	27.7
	5%	15.2	29.4	448	.0533	2.87	.300	2.13
West South Central	10%	30.5	58.7	896	.107	5.73	.600	4.26
	20%	60.9	117	1790	.213	11.5	1.20	8.52

Table 18. Fuel Saved by Process and Region - Proportional Fuel Replacement*

Region	Wind Capacity	Steam			Turbine		Internal Combustion	
		Coal	Oil	Gas	Oil	Gas	Oil	Gas
	5%	.318	23.8	1.52	.734	.113	.162	.158
New England	10%	.636	47.6	3.05	1.47	.227	.325	.315
	20%	1.27	95	6.10	2.94	.454	.649	.631
	5%	9.83	29.4	13.7	6.94	9.79	.110	.110
Middle Atlantic	10%	19.7	58.8	27.5	13.9	19.6	.221	.219
	20%	39.3	118	55	27.8	39.2	.441	.439
	5%	27	4.36	17.3	1.95	14.3	.217	1.80
East North Central	10%	54	8.72	34.6	3.90	28.6	.433	3.59
	20%	108	17.4	69.1	7.79	57.2	.867	7.19
	5%	12.5	.964	130	.578	7.41	.306	8.33
West North Central	10%	25	1.93	260	1.16	14.8	.613	16.7
	20%	50	3.86	520	2.31	29.6	1.23	33.3
	5%	1.13	5.01	453	.0129	4.13	.0614	2.58
West South Central	10%	2.26	10	905	.0259	8.27	.123	5.16
	20%	4.53	20	1810	.0518	16.5	.245	10.3

* Units: Coal, 10^5 Tons; Oil, 10^5 Bbls; Gas, 10^5 Mcf.

Table 19. Reduced Emissions of SO_x by Region and Process - Proportional Fuel Replacement (10^5 Lb)

Region	Wind Capacity	Steam			Turbine and Int. Combustion	
		Coal	Oil	Gas	Oil	Gas
New England	5%	15	114	.000821	.119	.00127
	10%	30	229	.00165	.237	.00254
	20%	59.8	457	.00329	.474	.00508
Middle Atlantic	5%	699	141	.00740	.931	.0463
	10%	1400	283	.0148	1.86	.0928
	20%	2790	568	.0297	3.73	.186
East North Central	5%	2520	21	.00934	.286	.0753
	10%	5040	41.9	.0187	.572	.151
	20%	10100	83.7	.0373	1.14	.301
West North Central	5%	1000	6.95	.0702	.117	.0737
	10%	2000	13.9	.140	.234	.147
	20%	4000	27.8	.281	.467	.294
West South Central	5%	22.8	21	.245	.00981	.0314
	10%	45.7	42	.489	.0197	.0629
	20%	91.5	84	.977	.0392	.125

Table 20. Reduced Emissions of NO_x by Region and Process - Proportional Fuel Replacement (10^5 Lb)

Region	Wind Capacity	Steam			Turbine and Int. Combustion	
		Coal	Oil	Gas	Oil	Gas
New England	5%	6.33	105	.593	2.55	.112
	10%	12.7	210	1.19	5.12	.224
	20%	25.3	419	2.38	10.2	.448
Middle Atlantic	5%	188	130	5.34	20.1	4.09
	10%	376	259	10.7	40.2	8.18
	20%	751	520	21.4	80.5	16.4
East North Central	5%	478	19.2	6.75	6.18	6.65
	10%	956	38.5	13.5	12.3	13.3
	20%	1910	76.9	26.9	24.7	26.6
West North Central	5%	198	4.25	50.7	2.52	6.48
	10%	395	8.50	101	5.05	13
	20%	790	17	203	10.1	26
West South Central	5%	12.7	22.1	177	.212	2.77
	10%	25.3	44.1	353	.424	5.53
	20%	50.7	88.2	706	.846	11.1

Table 21. Reduced Emissions of CO by Region and Process - Proportional Fuel Replacement (10^3 Lb)

Region	Wind Capacity	Steam			Turbine and Int. Combustion	
		Coal	Oil	Gas	Oil	Gas
New England	5%	15.9	4	.0608	58	3.12
	10%	31.8	8	.122	116	6.23
	20%	63.6	16	.244	232	12.4
Middle Atlantic	5%	1440	2.30	.548	456	114
	10%	2880	4.62	1.10	912	228
	20%	5780	9.24	2.20	1820	455
East North Central	5%	1190	.732	.692	140	185
	10%	2380	1.46	1.38	280	370
	20%	4750	2.93	2.76	560	741
West North Central	5%	500	.162	5.20	57.2	181
	10%	1000	.324	10.4	115	362
	20%	2000	.648	20.8	229	723
West South Central	5%	31.6	.842	18.1	4.81	77.2
	10%	63.3	1.68	36.2	9.64	154
	20%	127	3.36	72.4	19.2	308

Table 22. Reduced Emissions of HC by Region and Process - Proportional Fuel Replacement (10^4 Lb)

Region	Wind Capacity	Steam Coal	Steam Oil	Steam Gas	Turbine and Int. Combustion Oil	Turbine and Int. Combustion Gas
	5%	.553	20	.608	2.10	.114
New England	10%	1.11	40	1.22	4.19	.228
	20%	2.21	79.8	2.44	8.40	.455
	5%	16.5	24.7	5.48	16.5	4.16
Middle Atlantic	10%	33.1	49.4	11	33.8	8.32
	20%	66	99.1	22	66	16.6
	5%	41.6	3.66	6.92	5.08	6.76
East North Central	10%	83.2	7.32	13.8	10.1	13.5
	20%	166	14.6	27.6	20.3	27
	5%	17.2	.810	52	2.07	6.59
West North Central	10%	34.5	1.62	104	4.14	13.2
	20%	69	3.24	208	8.28	26.4
	5%	1.11	4.21	181	.174	2.82
West South Central	10%	2.21	8.40	362	.349	5.63
	20%	4.44	16.8	724	.695	11.3

Table 23. Reduced Emissions of Aldehydes by Region and Process - Proportional Fuel Replacement (10^3 Lb)

Region	Wind Capacity	Steam			Turbine and Int. Combustion	
		Coal	Oil	Gas	Oil	Gas
	5%	.158	100	.456	ND	ND
New England	10%	.317	200	.915	ND	ND
	20%	.633	399	1.83	ND	ND
	5%	4.71	123	4.11	ND	ND
Middle Atlantic	10%	9.42	247	8.25	ND	ND
	20%	18.8	496	16.5	ND	ND
	5%	11.9	18.3	5.19	ND	ND
East North Central	10%	23.8	36.6	10.4	ND	ND
	20%	47.6	73.2	20.7	ND	ND
	5%	4.95	4.05	39	ND	ND
West North Central	10%	9.90	8.11	78	ND	ND
	20%	19.8	16.2	156	ND	ND
	5%	.316	21	136	ND	ND
West South Central	10%	.633	42	272	ND	ND
	20%	1.27	84	543	ND	ND

ND: No Data

Table 24. Reduced Emissions of Particulates by Region and Process-Proportional Fuel Replacement (10^4 Lb)

Region	Wind Capacity	Steam			Turbine and Int. Combustion	
		Coal	Oil	Gas	Oil	Gas
	5%	79.5	15.9	.0456	.376	.00759
New England	10%	159	31.9	.0915	.756	.0152
	20%	318	63.6	.183	1.51	.0304
	5%	7350	19.7	.411	2.96	.277
Middle Atlantic	10%	14700	39.4	.825	5.92	.554
	20%	29500	79.1	1.65	11.8	1.11
	5%	6750	2.92	.519	.911	.451
East North Central	10%	13500	5.84	1.04	1.82	.902
	20%	27000	11.7	2.07	3.64	1.80
	5%	3120	.646	3.90	.371	.440
West North Central	10%	6250	1.29	7.80	.743	.882
	20%	12500	2.59	15.6	1.49	1.76
	5%	282	3.36	13.6	.312	.188
West South Central	10%	565	6.70	27.2	.626	.375
	20%	1130	13.4	54.3	1.25	.750

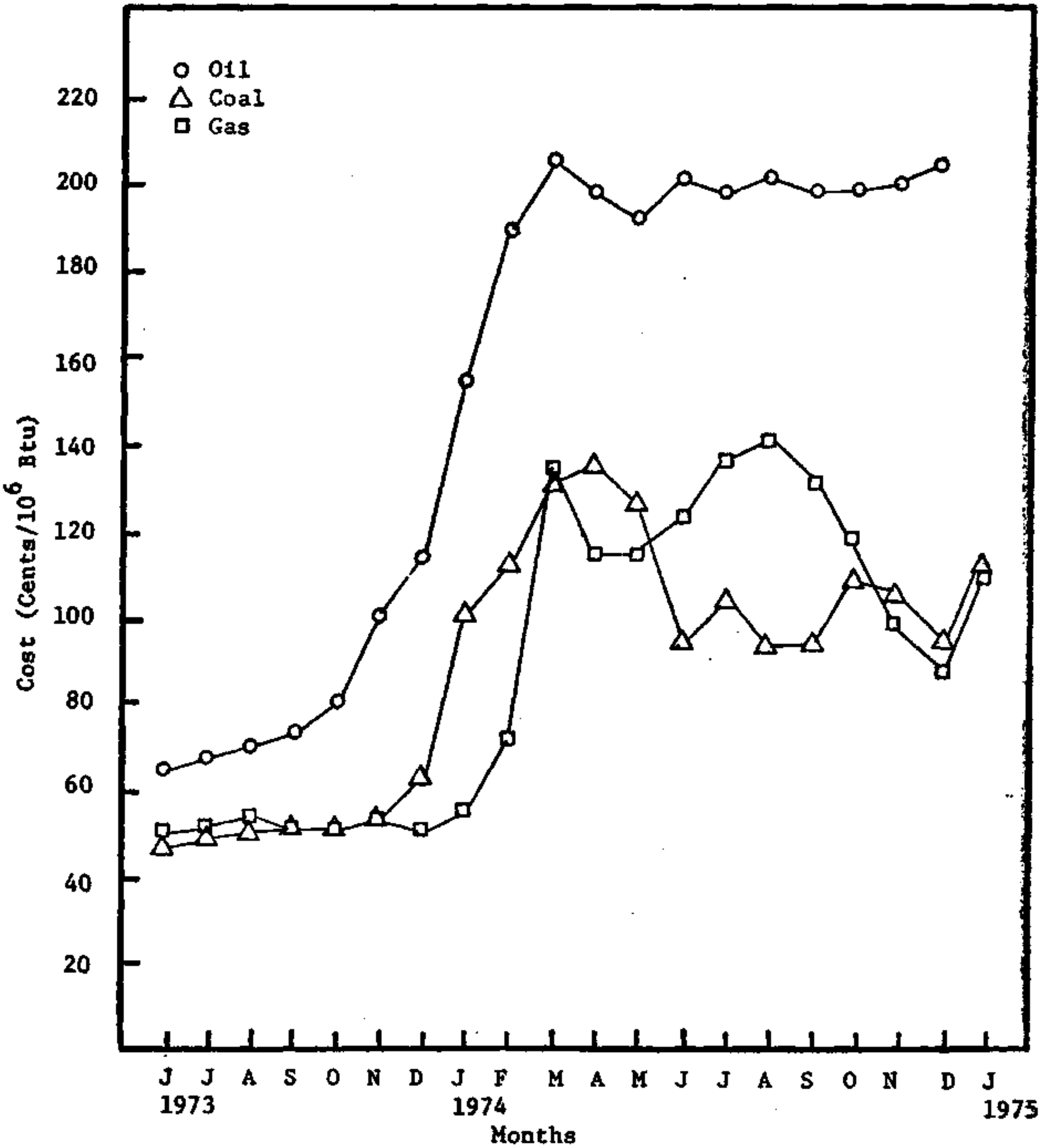

Figure 4. Cost of Fuel for the New England Region.

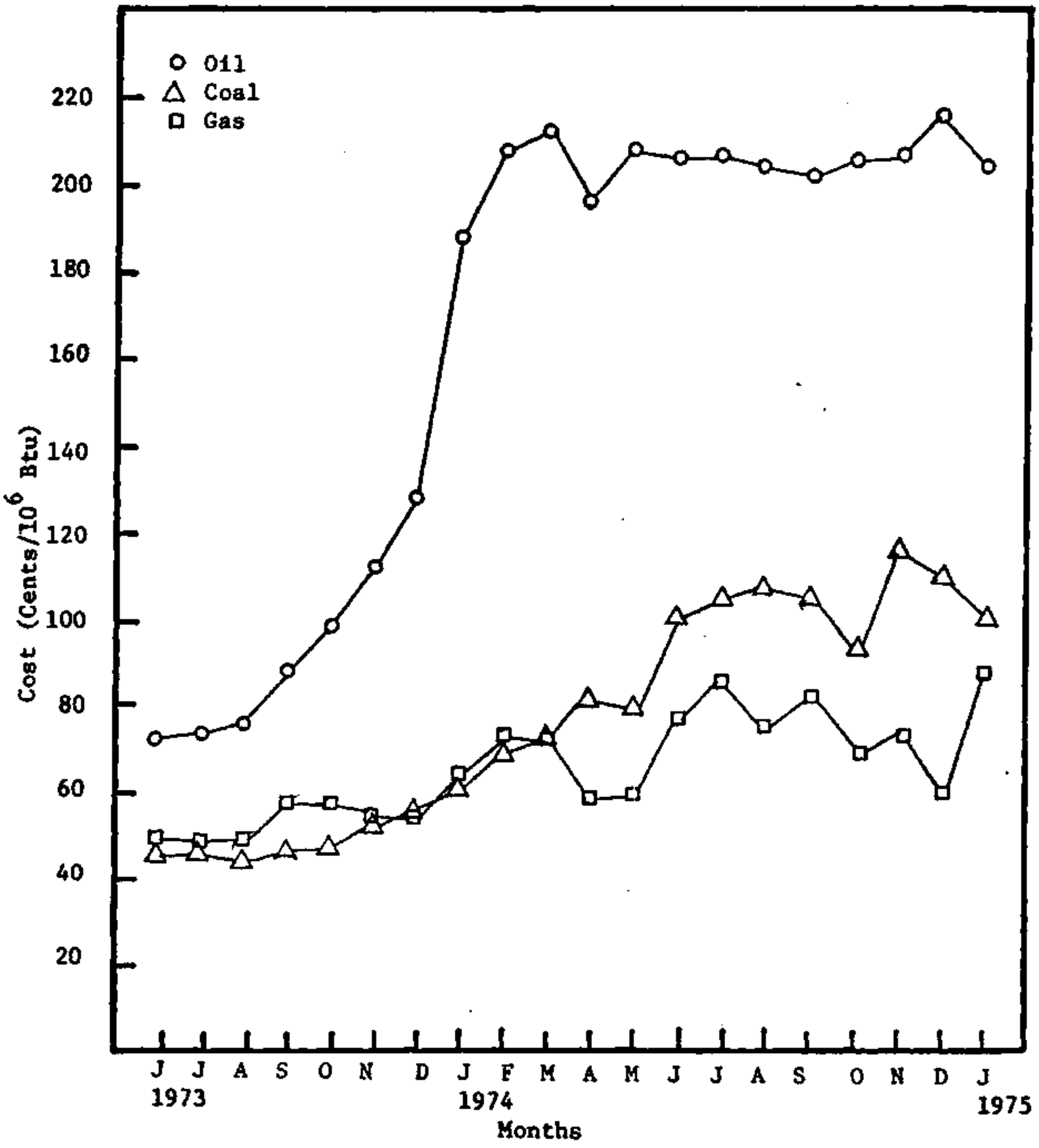

Figure 5. Cost of Fuel for the Middle Atlantic Region.

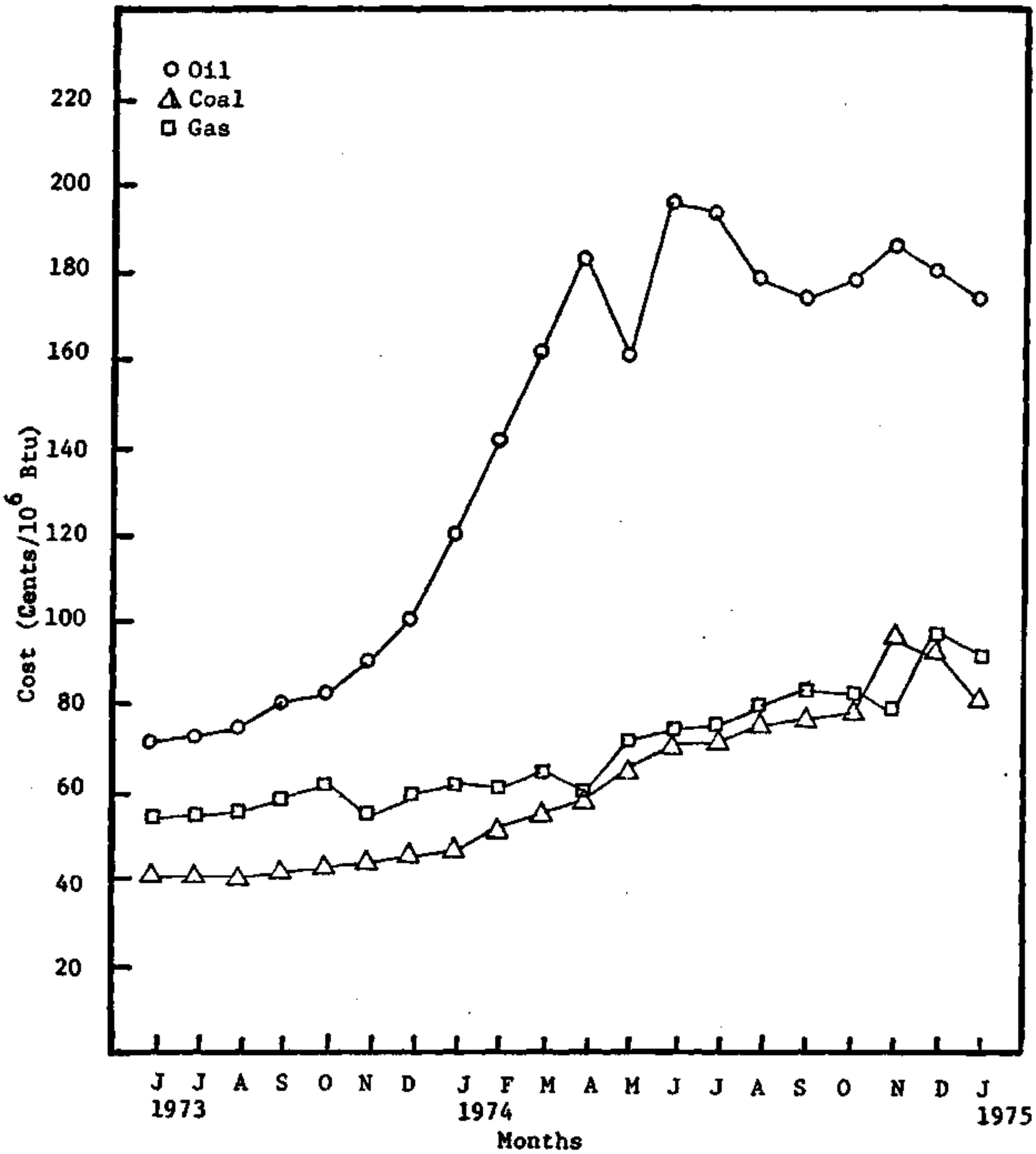

Figure 6. Cost of Fuel for the East North Central Region.

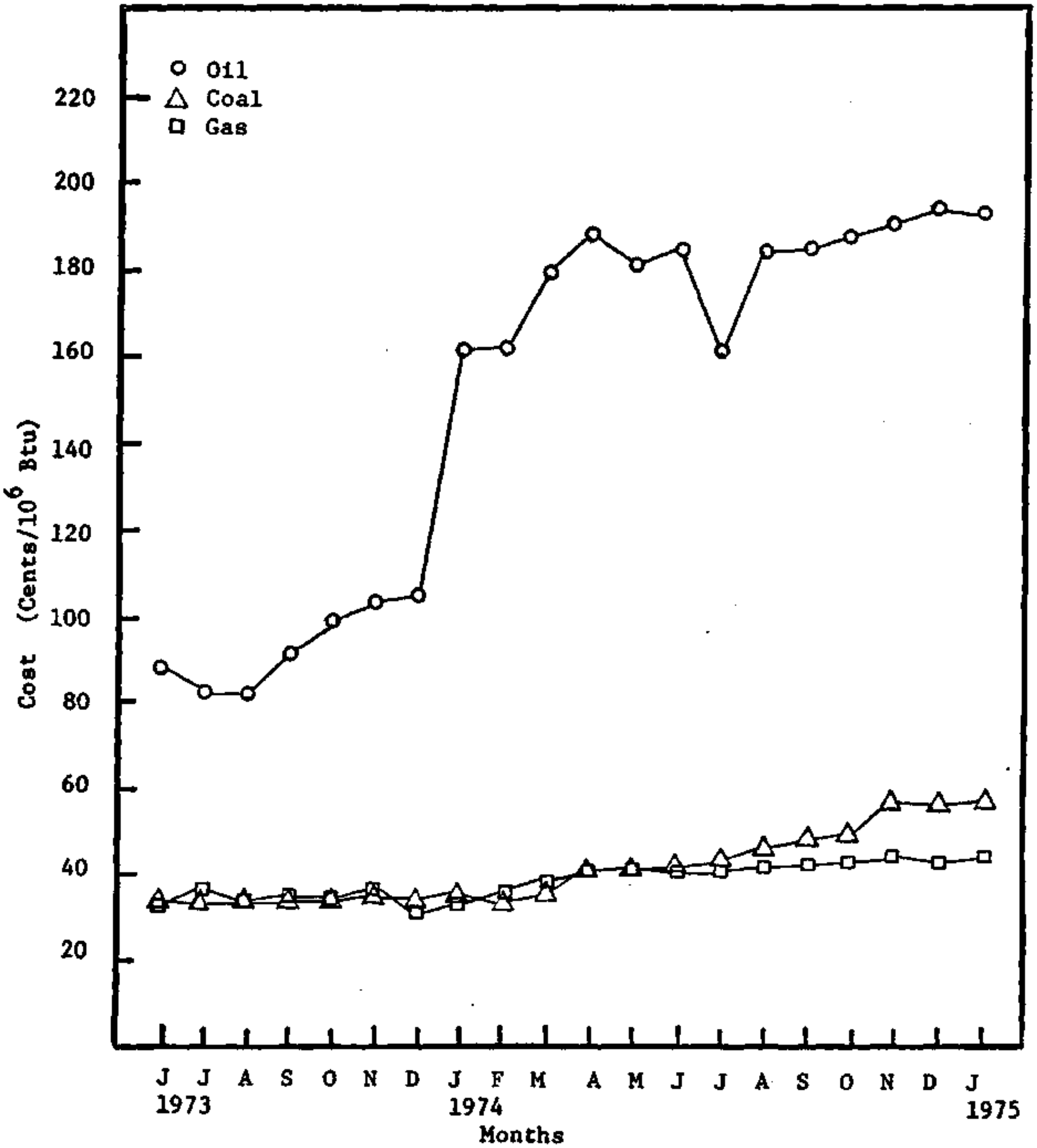

Figure 7. Cost of Fuel for the West North Central Region.

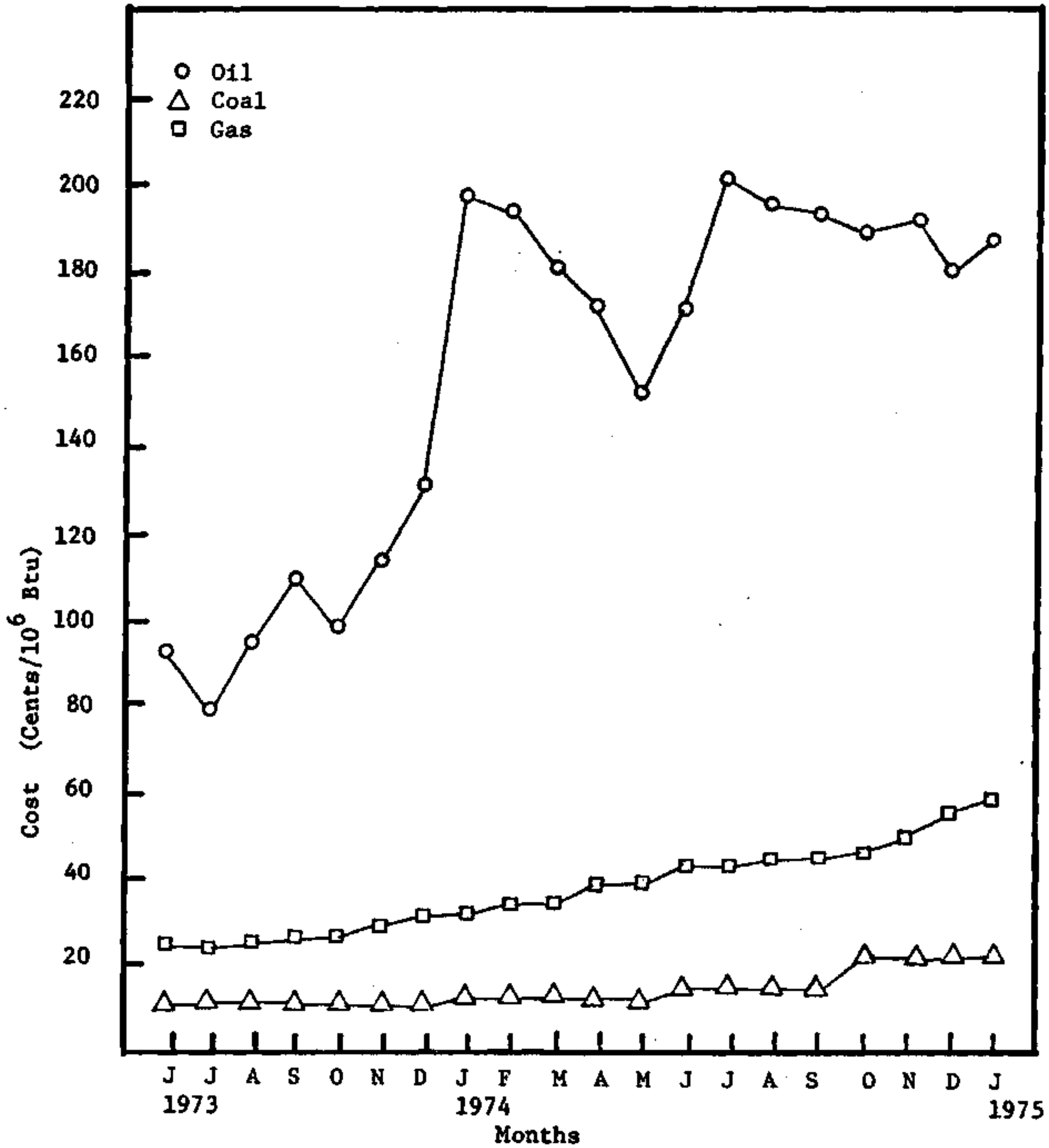

Figure 8. Cost of Fuel for the West South Central Region.

Table 25. Cost of Fuel by Region (Cents/10^6Btu)

Region	Coal	Oil	Gas
New England	105	200	120
Middle Atlantic	110	205	80
East North Central	85	185	90
West North Central	55	195	45
West South Central	20	190	55

Table 26. Cost of Fuel by Region and Process (Cents/kWh)

Region	Steam			Turbine		Int. Combustion	
	Coal	Oil	Gas	Oil	Gas	Oil	Gas
New England	1.12	2.13	1.28	3.23	1.94	2.37	1.42
Middle Atlantic	1.17	2.18	.85	3.32	1.29	2.28	.89
East North Cent.	.88	1.91	.93	2.79	1.36	1.96	.95
West North Cent.	.62	2.20	.51	2.95	.68	2.33	.54
West South Cent.	.21	1.98	.57	2.82	.82	2.37	.69

Table 27. Energy Distribution by Process and Region - Most Expensive Fuel Replacement (10^7 kWh)

Region	Wind Capacity	Steam Coal	Steam Oil	Steam Gas	Turbine Oil	Turbine Gas	Internal Combustion Oil	Internal Combustion Gas
New England	5%	0	58.4	0	64.6	0	26.7	0
	10%	0	208	0	64.6	0	26.7	0
	20%	0	507	0	64.6	0	26.7	0
Middle Atlantic	5%	0	0	0	438	0	0	0
	10%	0	27.7	0	821	0	27.6	0
	20%	0	705	0	821	0	27.6	0
East North Central	5%	0	307	0	268	0	60	0
	10%	0	943	0	268	0	60	0
	20%	0	1274	586	268	282	60	71.6
West North Central	5%	7.04	151	0	50.6	103	42.9	0
	10%	362	151	0	50.6	103	42.9	0
	20%	1072	151	0	50.6	103	42.9	0
West South Central	5%	0	486	0	1.56	0	10.5	0
	10%	0	983	0	1.56	0	10.5	0
	20%	0	1230	590	1.56	84.2	10.5	74.4

Table 28. Fuel Saved by Process and Region - Most Expensive Fuel Replacement *

Region	Wind	Steam			Turbine		Internal Combustion	
	Capacity	Coal	Oil	Gas	Oil	Gas	Oil	Gas
	5%	0	10.1	0	17	0	5.17	0
New England	10%	0	36.1	0	17	0	5.17	0
	20%	0	88	0	17	0	5.17	0
	5%	0	0	0	116	0	0.	0
Middle Atlantic	10%	0	4.82	0	218	0	5.04	0
	20%	0	157	0	218	0	5.04	0
	5%	0	52.1	0	66.3	0	10.4	0
East North Central	10%	0	160	0	66.3	0	10.4	0
	20%	0	216	689	66.3	483	10.4	86.5
	5%	.401	27.4	0	12.3	157	8.23	0
West North Central	10%	20.6	27.4	0	12.3	157	8.23	0
	20%	61.1	27.4	0	12.3	157	8.23	0
	5%	0	82.8	0	.379	0	2.14	0
West North Central	10%	0	168	0	.379	0	2.14	0
	20%	0	210	597	.379	121	2.14	90.2

* Units: Coal, 10^5 Tons; Oil, 10^5 Bbls; Gas, 10^5 Mcf.

Table 29. Reduced Emissions of SO_x by Region and Process - Most Expensive Fuel Replacement (10^5 Lb)

Region	Wind	Steam			Turbine		Internal Combustion	
	Capacity	Coal	Oil	Gas	Oil	Gas	Oil	Gas
	5%	0	48.6	0	2.24	0	.682	0
New England	10%	0	174	0	2.24	0	.682	0
	20%	0	423	0	2.24	0	.682	0
	5%	0	0	0	15.3	0	0	0
Middle Atlantic	10%	0	23.2	0	28.8	0	.665	0
	20%	0	755	0	28.8	0	.665	0
	5%	0	251	0	8.75	0	1.37	0
East North Central	10%	0	770	0	8.75	0	1.37	0
	20%	0	1040	.372	8.75	2.26	1.37	.405
	5%	32.1	198	0	1.62	.735	1.09	0
West North Central	10%	1650	198	0	1.62	.735	1.09	0
	20%	4890	198	0	1.62	.735	1.09	0
	5%	0	348	0	.050	0	.282	0
West South Central	10%	0	706	0	.050	0	.282	0
	20%	0	882	.322	.050	.566	.282	.422

Table 30. Reduced Emissions of NO_x by Region and Process - Most Expensive Fuel Replacement (10^5 Lb)

Region	Wind Capacity	Steam Coal	Steam Oil	Steam Gas	Turbine Oil	Turbine Gas	Internal Combustion Oil	Internal Combustion Gas
New England	5%	0	44.5	0	48.4	0	14.7	0
	10%	0	159	0	48.4	0	14.7	0
	20%	0	388	0	48.4	0	14.7	0
Middle Atlantic	5%	0	0	0	331	0	0	0
	10%	0	21.4	0	621	0	14.4	0
	20%	0	692	0	621	0	14.4	0
East North Central	5%	0	230	0	189	0	29.6	0
	10%	0	706	0	189	0	29.6	0
	20%	0	953	269	189	199	29.6	35.7
West North Central	5%	6.34	121	0	35.1	64.8	23.5	0
	10%	325	121	0	35.1	64.8	23.5	0
	20%	965	121	0	35.1	64.8	23.5	0
West South Central	5%	0	365	0	1.08	0	6.10	0
	10%	0	741	0	1.08	0	6.10	0
	20%	0	926	247	1.08	50	6.10	37.3

Table 31. Reduced Emissions of CO by Region and Process - Most Expensive Fuel Replacement (10^3 Lb)

Region	Wind Capacity	Steam			Turbine		Internal Combustion	
		Coal	Oil	Gas	Oil	Gas	Oil	Gas
	5%	0	1.70	0	1100	0	334	0
New England	10%	0	6.06	0	1100	0	334	0
	20%	0	14.8	0	1100	0	334	0
	5%	0	0	0	7510	0	0	0
Middle Atlantic	10%	0	.810	0	14100	0	326	0
	20%	0	26.4	0	14100	0	326	0
	5%	0	8.75	0	4290	0	673	0
East North Central	10%	0	26.9	0	4290	0	673	0
	20%	0	36.3	27.6	4290	5550	673	13.3
	5%	16.	4.60	0	796	1810	532	0
West North Central	10%	824	4.60	0	796	1810	532	0
	20%	2440	4.60	0	796	1810	532	0
	5%	0	13.9	0	24.5	0	138	0
West South Central	10%	0	28.2	0	24.5	0	138	0
	20%	0	35.3	23.9	24.5	1390	138	1040

Table 32. Reduced Emissions of HC by Region and Process - Most Expensive Fuel Replacement (10^4 Lb)

Region	Wind	Steam			Turbine		Internal Combustion	
	Capacity	Coal	Oil	Gas	Oil	Gas	Oil	Gas
	5%	0	8.48	0	40	0	12.1	0
New England	10%	0	30.3	0	40	0	12.1	0
	20%	0	73.9	0	40	0	12.1	0
	5%	0	0	0	271	0	0	0
Middle Atlantic	10%	0	4.05	0	510	0	11.8	0
	20%	0	132	0	510	0	11.8	0
	5%	0	43.8	0	155	0	24.3	0
East North Central	10%	0	134	0	155	0	24.3	0
	20%	0	181	276	155	203	24.3	36.3
	5%	.553	23	0	28.8	65.9	19.3	0
West North Central	10%	28.4	23	0	28.8	65.9	19.3	0
	20%	84.3	23	0	28.8	65.9	19.3	0
	5%	0	69.6	0	.887	0	5.01	0
West South Central	10%	0	141	0	.887	0	5.01	0
	20%	0	176	239	.887	50.8	5.01	37.9

Table 33. Reduced Emissions of Aldehydes by Region and Process–Most Expensive Fuel Replacement (10^3 Lb)

Region	Wind Capacity	Steam Coal	Steam Oil	Steam Gas	Turbine Oil	Turbine Gas	Internal Combustion Oil	Internal Combustion Gas
New England	5%	0	42.4	0	ND	ND	ND	ND
	10%	0	152	0	ND	ND	ND	ND
	20%	0	370	0	ND	ND	ND	ND
Middle Atlantic	5%	0	0	0	ND	ND	ND	ND
	10%	0	20.2	0	ND	ND	ND	ND
	20%	0	659	0	ND	ND	ND	ND
East North Central	5%	0	219	0	ND	ND	ND	ND
	10%	0	672	0	ND	ND	ND	ND
	20%	0	907	207	ND	ND	ND	ND
West North Central	5%	.159	115	0	ND	ND	ND	ND
	10%	10.3	115	0	ND	ND	ND	ND
	20%	24.2	115	0	ND	ND	ND	ND
West South Central	5%	0	348	0	ND	ND	ND	ND
	10%	0	706	0	ND	ND	ND	ND
	20%	0	882	179	ND	ND	ND	ND

ND: No data.

Table 34. Reduced Emissions of Particulates by Region and Process- Most Expensive Fuel Replacement(10^4Lb)

Region	Wind Capacity	Steam Coal	Steam Oil	Steam Gas	Turbine Oil	Turbine Gas	Internal Combustion Oil	Internal Combustion Gas
	5%	0	6.77	0	7.14	0	2.17	0
New England	10%	0	24.2	0	7.14	0	2.17	0
	20%	0	59	0	7.14	0	2.17	0
	5%	0	0	0	48.7	0	0	0
Middle Atlantic	10%	0	3.23	0	91.6	0	2.12	0
	20%	0	105	0	91.6	0	2.12	0
	5%	0	34.9	0	27.8	0	4.37	0
East North Central	10%	0	107	0	27.8	0	4.37	0
	20%	0	145	20.7	27.8	12.3	4.37	2.42
	5%	100	18.4	0	5.17	4.40	3.46	0
West North Central	10%	5150	18.4	0	5.17	4.40	3.46	0
	20%	15300	18.4	0	5.17	4.40	3.46	0
	5%	0	55.5	0	.159	0	.899	0
West South Central	10%	0	113	0	.159	0	.899	0
	20%	0	141	17.9	.159	3.39	.899	2.53

Table 35. Savings Due to Fuel Saved (10^6 Dollars)

Region	Wind Capacity	Proportional Fuel Replacement Coal	Oil	Gas	Total	Most Expensive Fuel Replacement Coal	Oil	Gas	Total
	5%	.832	30.3	.215	31.3	0	39.5	0	39.5
New England	10%	1.66	60.5	.431	62.6	0	71.4	0	71.4
	20%	3.32	121	.862	125	0	135	0	135
	5%	25.9	45.6	2.05	73.6	0	145	0	145
Middle Atlantic	10%	51.9	91.2	4.12	147.2	0	285	0	285
	20%	103	183	8.23	294	0	475	0.	475
	5%	50.7	7.36	2.64	60.7	0	145	0	145
East North Central	10%	101	14.7	5.28	121	0	267	0	267
	20%	203	29.4	10.5	243	0	330	99.4	429
	5%	13.6	2.24	6.56	22.4	.436	58.1	7.06	65.6
West North Central	10%	27.2	4.49	13.1	44.8	22.4	58.1	7.06	87.6
	20%	54.4	8.98	26.2	89.6	66.5	58.1	7.06	132
	5%	.316	5.89	26.2	32.4	0	98.9	0	98.9
West South Central	10%	.633	11.8	52.4	64.8	0	198	0	198
	20%	1.27	23.5	105	13.	0	246	46.1	292

CHAPTER VII

ECONOMIC ESTIMATES

Damage costs for air pollution were taken from two sources, Justus et al., (1973) and Waddell (1974). Both of these reports estimate the damage, in terms of dollars, due to air pollution for 1970. Each report considers damage to health, materials, plants, animals, property values, soiling and visibility due to particulates, SO_x, NO_x, HC, and CO. These two estimates are shown in Table 36 and Table 37.

To be of any use here, the damage costs for each pollutant must be related to the source as only emissions from electric power generation are dealt with here. Since the damage resulting from the same amount of pollutant from different sources is not the same, some type of weighting factor must be used. Scorer (1965) has developed such factors for use in Britain. Justus et al., (1973) modified these factors somewhat for use in the United States.

The damage cost for each source is taken to be proportional to the emission rate and the source weighting factor and normalized so that the total cost for each pollutant will remain the same as in Table 36 and Table 37. Using the 1970 emissions and source factors in Table 38 with the damage estimates of Justus et al., (1973) and Waddell (1974) given damage cost by pollutant and source, which is then divided by the emissions to get cost in dollars per ton of emission. These values for electric power generation are given in Table 39. The cost estimates are then multiplied by the reduced emissions to obtain total cost savings due to wind power. (See Table 40 - Table 45).

Table 36. Nationwide Air Pollution Damage Costs for 1970, billion dollars (Waddell, 1974)

Effect	SO_x			Particulate			NO_x and HC			CO	Total		
	Low	High	Best	Low	High	Best	Low	High	Best	Best	Low	High	Best
Aesthetics & soiling[a,b]	1.7	4.1	2.9	1.7	4.1	2.9	?	?	?	*	3.4	8.2	5.8
Human health	0.7	3.1	1.9	0.9	4.5	2.7	?	?	?	?	1.6	7.6	4.6
Materials [b]	0.4	0.8	0.6	0.1	0.3	0.2	0.5	1.3	0.9	*	1.0	2.4	1.7
Vegetation	*	*	*	*	*	*	0.1	0.3	0.2	*	0.1	0.3	0.2
Animals	?	?	?	?	?	?	?	?	?	*	?	?	?
Natural environment	?	?	?	?	?	?	?	?	?	?	?	?	?
Total	2.8	8.0	5.4	2.7	8.9	5.8	0.6	1.6	1.1		6.1	18.5	12.3

Notes:

[a] Property value estimator

[b] Adjusted to minimize double-counting

?Unknown

*Negligible

Table 37. Nationwide Air Pollution Damage Costs For 1970
(June 1973)

Damage Effect	Damage Cost Range (10^6 dollars)					
	PM	SO_2	NO_2	HC	CO	Total
Health	8 - 41	1 - 4	0 - 1	44 - 221	9 - 44	62 - 311
Materials	169 - 767	215 - 972	52 - 236	254 - 791	30 - 134	720 - 2900
Plants	10	4	2	116	0	132
Animals	1 - 3	0	0	4 - 11	0 - 2	3 - 16
Property Values	300 - 1765	126 - 745	47 - 275	67 - 399	19 - 114	559 - 3298
Soiling	519 - 2077	0	0	0	0	519 - 2077
Visibility	0	0	0	0	0	0
Total	1007 - 4663	346 - 1725	101 - 514	483 - 1538	58 - 294	1995 - 8734

Table 38. Total Emissions and Source Factors for 1970
(June, 1973)

	PM	SO_2	NO_2	HC	CO	Source Factor W
Transportation	0.7	1	11.7	19.5	111	40
Electric Power Generation	3	15	3	0.03	0.1	1
Industrial Combustion	3.4	9.3	6.8	0.4	0.1	6
Industrial Processes	13.1	6	0.2	5.5	11.4	6
Domestic Heating	0.4	2.2	0.2	0.2	0.6	40
Refuse Disposal	1.4	0.1	0.4	2.[illegible]	7.2	6
Miscellaneous	3.4	0.3	0.4	7.1	16.8	10
	25.4	33.9	22.7	34.7	147.2	

Table 39. Damage Costs in $/Ton for Electric Power Generation

	Particulates		SO_x		NO_x		HC		CO	
	Low	High	Low	High	Low	High	Low	High	Low	High
Justus	5.35	24.75	1.45	7.24	.192	.972	.533	1.70	.0122	.0620

	Particulates			SO_x			NO_x and HC			CO
	Low	High	Best	Low	High	Best	Low	High	Best	
Waddell	14.33	47.24	30.78	11.74	33.56	22.65	.418	1.12	.767	0

Table 40. Reduced Emissions by Pollutant and Region - Proportional Fuel Replacement (10^2 tons)

Region	Wind Capacity	SO_x	NO_x	CO	HC*	Particulates
New England	5%	64.6	57.3	.405	1.67	4.79
	10%	130	115	.811	3.35	9.58
	20%	259	229	1.62	6.69	19.2
Middle Atlantic	5%	420	174	10.1	4.03	369
	10%	842	348	20.1	8.05	737
	20%	1680	695	40.3	16.2	1470
East North Central	5%	1270	258	7.58	3.38	338
	10%	2540	517	15.2	6.75	675
	20%	5080	1030	30.3	13.5	1350
West North Central	5%	504	131	3.72	4.17	156
	10%	1010	262	7.44	8.35	313
	20%	2010	524	14.9	16.7	625
West South Central	5%	22	107	.663	10.3	15
	10%	44.1	215	1.33	20.5	29.9
	20%	88.2	430	2.65	41.0	59.8

* Includes Aldehydes.

Table 41. Cost Savings Using Justus' Damage Estimates - Proportional Fuel Replacement (10^3 dollars).

Region	Wind Capacity	SO_x		NO_x		CO		HC*		Particulates		Total	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	high
New England	5%	9.37	46.8	1.10	5.59	.0005	.0025	.0890	.284	2.56	11.9	13.1	64.6
	10%	18.8	93.8	2.20	11.2	.0010	.0050	.178	.569	5.13	23.7	26.3	129
	20%	37.5	187	4.40	22.3	.0020	.0101	.356	1.14	10.3	47.4	52.6	258
Middle Atlantic	5%	61	304	3.34	16.9	.0123	.0624	.215	.685	197	912	262	1234
	10%	122	610	6.67	33.9	.0246	.125	.429	1.37	394	1820	523	2465
	20%	244	1220	13.3	67.8	.0491	.250	.861	2.75	789	3650	1047	4941
East North Central	5%	184	920	4.96	25.2	.0092	.0472	.180	.574	181	876	370	1822
	10%	368	1840	9.92	50.4	.0185	.0940	.360	1.15	361	1670	739	3562
	20%	737	3680	19.8	101	.0370	.188	.722	2.30	722	3340	1480	7123
West North Central	5%	73	365	2.51	12.8	.0045	.0231	.222	.709	83.6	387	159	766
	10%	146	729	5.03	25.5	.0091	.0461	.445	1.42	167	774	318	1530
	20%	292	1460	10.1	51.1	.0181	.0922	.890	2.84	334	1550	637	3064
West South Central	5%	3.20	16	2.06	10.5	.0008	.0041	.547	1.74	8.20	37	14	65.2
	10%	6.39	31.9	4.12	20.9	.0016	.0082	1.09	3.49	16.0	74	27.6	130
	20%	12.8	63.8	8.25	41.9	.0032	.0164	2.19	6.97	32.0	148	55.2	261

* Includes Aldehydes.

Table 42. Cost Savings Using Waddell's Damage Estimate - Proportional Fuel Replacement (10^3 dollars)

Region	Wind Capacity	SO_x Low	SO_x High	SO_x Best	Particulates Low	Particulates High	Particulates Best	NO_x and HC* Low	NO_x and HC* High	NO_x and HC* Best	CO	Total Low	Total High	Total Best
New England	5%	75.8	217	146	6.87	22.6	14.7	2.46	6.60	4.52	0	85.1	246	165
	10%	152	435	294	13.7	45.3	29.5	4.93	13.2	9.05	0	171	493	333
	20%	304	868	586	27.5	90.5	59	9.86	26.4	18.1	0	341	985	663
Middle Atlantic	5%	494	1410	952	528	1740	1130	7.44	19.9	13.7	0	1029	3170	2102
	10%	989	2830	1910	1060	3480	2270	14.9	39.9	27.3	0	2064	6350	4207
	20%	1970	5640	3810	2110	6970	4540	29.8	79.8	54.6	0	4110	12690	8405
East North Central	5%	1490	4260	2880	484	1600	1040	10.9	29.3	20	0	1995	5889	3940
	10%	2990	8530	5760	968	3190	2080	21.9	58.5	40.1	0	3980	11778	7880
	20%	5970	17100	11500	1940	6380	4160	43.7	117	80.2	0	7954	23597	15742
West North Central	5%	591	1690	1140	224	738	481	5.65	15.1	10.4	0	820	2443	1631
	10%	1180	3380	2280	448	1480	962	11.3	30.4	20.7	0	1639	4890	3272
	20%	2360	6760	4560	896	2950	1920	22.6	60.6	41.5	0	3299	9771	6522
West South Central	5%	25.9	74	49.9	21.4	70.7	46	4.90	13.1	9	0	52.2	159	105
	10%	51.8	148	999	42.9	141	92.1	9.81	26.3	18	0	105	315	1109
	20%	104	296	200	85.7	283	184	19.6	52.6	36	0	209	632	420

* Includes Aldehydes.

Table 43. Reduced Emission by Pollutant and Region - Most Expensive Fuel Replacement (10^2 tons).

Region	Wind Capacity	SO_x	NO_x	CO	HC*	Particulates
New England	5%	25.8	53.8	7.18	3.24	.841
	10%	88.5	111	7.20	4.88	1.68
	20%	213.	226	7.24	8.15	3.42
Middle Atlantic	5%	7.65	166	37.6	13.6	2.43
	10%	26.3	328	72.1	26.4	4.85
	20%	892	664	72.3	36	9.94
East North Central	5%	131	224	24.86	12.2	3.35
	10%	390	462	24.94	19	6.96
	20%	527	838	53	49.4	10.6
West North Central	5%	117	125	15.8	7.45	6.57
	10%	926	285	19.8	8.90	259
	20%	2550	605	27.9	11.8	767
	5%	174	186	.882	5.51	2.83
	10%	353	374	.954	16.9	5.70
	20%	442	634	13.3	30.8	8.29

* Includes Aldehydes

Table 44. Cost Savings Using Justus' Damage Estimate - Most Expensive Fuel Replacement (10^3 dollars)

Region	Wind Capacity	SO_x Low	SO_x High	NO_x Low	NO_x High	CO Low	CO High	HC* Low	HC* High	Particulates Low	Particulates High	Total Low	Total High
New England	5%	3.74	18.7	1.03	5.25	.00876	.0445	.173	.551	.430	1.99	5.38	26.5
	10%	12.8	64	2.13	10.8	.00878	.0446	.260	.830	.896	4.15	16.1	79.8
	20%	30.9	154	4.33	22	.00884	.0449	.434	1.39	1.83	8.45	37.5	186
Middle Atlantic	5%	1.11	5.54	3.18	16.1	.0458	.233	.722	2.30	1.30	6.03	6.36	30.2
	10%	3.82	19.4	6.31	32.1	.0880	.447	1.41	4.49	2.59	12	14.2	68.4
	20%	56.9	284	12.7	64.7	.0882	.448	1.92	6.12	5.32	24.6	76.9	380
East North Central	5%	18.9	94.5	4.31	21.9	.0303	.154	.653	2.08	1.79	8.30	25.7	127
	10%	56.6	282	8.88	45.1	.0304	.155	1.01	3.23	3.72	17.2	70.2	348
	20%	76.4	381	16.1	81.7	.0646	.328	2.63	8.39	5.69	26.3	101	498
West North Central	5%	16.9	84.6	2.41	12.2	.0193	.0979	.397	1.27	3.52	16.3	23.2	114
	10%	134	670	5.47	27.8	.0242	.123	.474	1.51	139	641	299	1340.
	20%	569	1840	11.6	59	.0341	.173	.627	2.00	410	1900	991	3801.
West South Central	5%	25.3	126	3.57	18.1	.00108	.00547	.284	.938	1.51	7	30.7	152
	10%	51.2	256	7.18	36.5	.00116	.00591	.580	1.85	3.05	14.1	62	308.
	20%	64.1	320	12.2	61.8	.0162	.0822	1.64	5.23	4.44	20.5	82.4	408.

* Includes Aldehydes.

Table 45. Cost Saving Using Waddell's Damage Estimate - Most Expensive Fuel Replacement (10^3 dollars).

Region	Wind Capacity	SO_x			Particulates			NO_x and HC*			CO	Total		
		Low	High	Best	Low	High	Best	Low	High	Best		Low	High	Best
New England	5%	30.4	86.5	58.3	1.15	3.80	2.47	2.38	6.39	4.37	0	33.9	96.7	65.1
	10%	104	297	200	2.40	7.92	5.16	4.84	13	8.89	0	111	318	214
	20%	250	715	432	4.89	16.1	10.5	9.79	26.2	18	0	265	757	461
Middle Atlantic	5%	8.98	25.7	17.3	3.49	11.5	7.49	7.51	20.1	13.8	0	20.10	57.2	38.6
	10%	30.9	88.4	59.6	6.95	22.9	14.9	14.9	39.7	27.2	0	52.8	151	102
	20%	460	1320	888	14.2	46.9	30.6	29.3	78.4	53.7	0	503	1445	972
East North Central	5%	153	438	296	4.81	15.8	10.3	9.87	26.5	18.1	0	168	480	324
	10%	458	1310	883	9.97	32.9	21.4	20.1	53.9	36.9	0	488	1397	988
	20%	618	1770	1190	15.2	50.2	32.7	37.1	99.4	68.1	0	670	1920	1291
West North Central	5%	137	392	265	9.41	31	20.2	5.54	14.8	10.2	0	152	438	295
	10%	1090	3110	2100	371	1220	797	12.3	32.9	22.5	0	1473	4363	2920
	20%	2990	8540	5770	1100	3620	2360	25.8	69.1	47.3	0	4116	12229	8177
West South Central	5%	204	585	394	4.05	13.4	8.70	8.01	21.4	14.7	0	216	620	417
	10%	415	1190	800	8.17	26.9	17.6	16.3	43.8	30	0	655	1261	848
	20%	519	1480	1000	11.9	39.2	25.5	27.8	74.5	51	0	559	1594	1077

* Includes Aldehydes.

CHAPTER VIII

CONCLUSIONS

From Figure 2 it is seen that for the 1 MW generator at 200 feet, a plant factor of .2 or greater can be obtained over a significant part of the country. This is an output of 200 KW for every 1 MW generator installed. Over the period of a year this will amount ot 1.75×10^6 kWh produced for every 1 MW unit installed. It can also be seen that approximately 2/3 of the country has a plant factor of .1 or greater.

The dollar savings are divided into two categories - (1) the savings due to fuel saved and (2) the savings due to lessened damages as a result of reduced emissions. The savings due to fuel saved (Table 35) are seen to be very much greater than the damage cost savings (Table 46). In the New England Region with 5% wind capacity the ratio of savings due to fuel saved and damage cost savings using Justus' estimates range from 480 to 2,390 for proportional fuel replacement and from 1,490 to 7,340 for most expensive fuel replacement. In the East North Central the ratio ranges from 33.32 to 164.05 for proportional fuel replacement and from 1,141 to 5,642 for most expensive fuel replacement.

From Table 35 it is seen that the spread of the

Table 46. Summary of Total Damage Costs. (10^3 Dollars)

Region	Wind Capacity	Justus Proportional Low	Justus Proportional High	Justus Most Expensive Low	Justus Most Expensive High	Waddell Proportional Low	Waddell Proportional High	Waddell Proportional Best	Waddell Most Expensive Low	Waddell Most Expensive High	Waddell Most Expensive Best
	5%	13.1	64.6	5.38	26.5	85.1	246	165	33.9	96.7	65.1
New England	10%	26.3	129	16.1	79.8	171	493	333	111	318	214
	20%	52.6	258	37.5	186	341	985	663	265	757	462
	5%	262	1234	6.36	30.2	1029	3170	2102	20	57.2	38.6
Middle Atlantic	10%	523	2465	14.2	68.4	2064	6350	4207	52.8	151	102
	20%	1047	4941	76.9	380	4140	12690	8405	503	1445	972
	5%	370	1822	25.7	127	1985	5889	3940	168	480	324
East North Central	10%	739	3562	70.2	343	3980	11778	7880	488	1397	941
	20%	1480	7123	101	498	7954	23597	15740	670	1920	1291
	5%	159	766	23.2	114	820	2443	1631	152	438	295
West North Central	10%	318	1530	279	1340	1639	4690	3272	1473	4363	2920
	20%	637	3064	991	3801	3279	9771	6522	4116	12229	8177
	5%	14	65.2	30.7	152	82.2	159	105	216	620	451
West South Central	10%	27.6	130	62	308	105	315	1109	655	1261	848
	20%	55.2	261	82.4	408	209	632	420	559	1594	1077

estimate of savings in a region (the lower bound being proportional fuel replacement and the upper bound being the most expensive fuel replacement) depends on the amounts of each fuel used. For example, in the New England region which produces a large percentage of its energy by oil, also the most expensive fuel, the difference between the two bounds is not very great - 31.3 to 39.5 million dollars for the 5% wind capacity. Whereas in the East North Central region which produces most of its energy by coal, the least expensive fuel, the two bounds differ greatly - 60.7 to 145 million dollars for the 5% wind capacity.

From Table 46 it is seen that the damage savings do not depend on the method of energy distribution as in fuel savings but depend on the emission factors. For example, in the New England, oil being the major fuel, results in less emissions of SO_x and particulates than in the East North Central region which uses mainly coal. Since SO_x and particulates do more damage, in terms of dollars/ton, then there will be more damage cost savings in the East North Central region than in the New England region. This is not true for the most expensive fuel replacement because oil is being replaced and it emits comparitively little SO_x and particulates. Also the higher damage cost savings result from proportional fuel replacement because the most expensive fuel replacement in each region is oil which produces less damaging pollutants. Damage cost savings using Justus' high estimate are

.472 dollars/10^{10}Btu consumed for the New England region and .391 dollars/10^{10} Btu consumed for the East North Central region using most expensive fuel replacement and 1.15 dollars/ 10^{10} Btu consumed for the new England region and 5.48 dollars/ 10^{10} Btu consumed for the East North Central region using proportional fuel replacement.

The data presented here are intended as a preliminary estimate of fuel cost savings and pollution damage cost savings which could be achieved through the implementation of wind power and electrical generation. More exact numbers can be obtained when sites are chosen and more is known about fuel replacement, cost of fuel and emissions from the particular equipment in use.

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